THE ADOPTION OF ADVANCED MANUFACTURING TECHNOLOGY AND STRATEGIC COMPLEXITY

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ABSTRACT

The properties inherent in Advanced Manufacturing Technology (AMT), create new opportunities for firms, and in particular small firms. The capability of these technologies to modify production specifications quickly and accurately means that firms can customise their products and attain economies of scope based on low volume and low cost production. While traditionally technology has been perceived merely as a tool in implementing business strategy, AMT has the potential to directly affect firm's strategy choices. To date however, empirical analysis to examine the technology-strategy relationship has not been forthcoming. This paper addresses this gap in the literature by synthesising current perspectives on the factors that determine strategy choice and so, integrate technology into the analysis.

The paper finds that AMT is instrumental in strategy choice. Yet, AMT does not behave uniformly, but instead the gains from lower-order technologies and their effect on firm's strategy will differ markedly from higher-order technologies. In addition, firm's must have an environment that is conducive to the adoption of higher order AMTs, otherwise this will lead to a narrowing of their business strategy and act as a constraint on growth. Alternatively, for firms pursuing a complex strategy, the introduction of AMTs will improve their strategic position by increasing their complexity and leading to flexibility gains in terms of business growth.

THE ADOPTION OF ADVANCED MANUFACTURING TECHNOLOGY AND STRATEGIC COMPLEXITY

1 Introduction

For many manufacturers whose plants and organisations were structured for the mass production of standardised products this has produced a crisis due to the "rigidity of long term and large scale fixed capital investments in mass production systems that preclude much flexibility of design and presumed stable growth in invariant consumer markets" (Harvey 1989:168). The challenge is to overcome these rigidities through the truncation of product life cycles, the shortening of production runs and the achievement of shorter lead times in both manufacturing and design (PA Consulting group 1989). The properties of advanced manufacturing technologies (AMT) overcome the limitations of conventional technology in enabling small firms to develop economies of scope based on low volume and low cost production. Specifically, AMTs facilitate customisation and reduced lead times through the production of "variety, frequent design changeovers, and rapid processing of design and market information" (Parthasarthy and Sethi 1992:101).

Advanced Manufacturing Technology (AMT) is broadly defined as "an automated production system of people, machines and tools for the planning and control of the production process, including the procurement of raw materials, parts and components and the shipment and service of finished products" (Pennings 1987:198). Computers are central to AMT in both storing and manipulating data. In general, AMT typically involves (a) a computer-aided design system (CAD) that develops designs, displays them and stores them for future reference; (b) a computer-aided manufacturing system (CAM) that translates CAD information for production and further controls machine tools, material flow, and testing; (c) an automative storage and retrieval system for delivery or pick up of parts between machines and storage; and (d) a supervisory computer that integrates all of the above (CIM) (Parthasarthy and Sethi 1992).

Despite evidence demonstrating the positive impact of AMT on business performance (Bessant and Haywood, 1988; Ingersol Engineers, 1984; Ettlie, 1988;

O'Toole, 1985; and Goldstein and Klein, 1987), considerable debate surrounds the role of technology in businesses' choice of market development strategy (Mauri and Michaels, 1988). From the perspective of the industrial organisation literature (eg. Bain, 1972; Caves, 1980; Demsetz, 1973; Clarke, 1985) technology is seen as having no impact on strategy choice with this being determined by market and industry structure. As Porter outlines, industry structure not only determines the rules of competition but also the "strategies potentially available to the firm" (1980:3). Similarly, Mintzberg (1979) suggests that decision making processes (or co-ordinating mechanisms) within a firm should be attuned to the complexity of the firm's business environment. In other words, firms operating in dynamic and fast growing markets will face markedly different competitive forces to firms in mature and stable markets.

An alternative perspective based on the resource based literature (Barney, 1991; Conner, 1991; Wernerfelt, 1984; Grant, 1991; Peteraf, 1993; Dooley et al.., 1996 Castrogiovanni, 1991) stresses the centrality of firm's internal resources in determining strategy choice, with particular emphasis on the role of technology. Skinner (1969, 1974, 1985), questioned the traditional view of technology in implementing business strategy, and instead argued that technology and other manufacturing competence's had to be accounted for in strategy formulation to avoid a mismatch between strategy and technology. More recently, Parthasarthy and Sethi (1992: 91) have called for "new conceptualisations that relate manufacturing technology and business strategy in interactive terms."

Despite various studies of the relationship between technology and strategy (Goldhar and Jelinek, 1985; Hayes and Jaikumar, 1988; Meredith, 1987; and Nemetz and Fry, 1988)
"empirical research that would validate the speculations that these studies make on the strategy-technology linkage has not been forthcoming" (Parthasarthy and Sethi, 1992: 88). This paper represents a first step in addressing this deficiency in the debate by empirically analysing the relationship between strategy and the use of AMT. The analysis is sensitive to both the industrial organisation and resource based perspectives of strategy formulation and examines the strategy-technology

relationship in the context of firm's market and industry structure and internal resource capabilities.

The remainder of this paper is organised as follows. Section 2 outlines the main conceptual framework and the hypotheses to be investigated. Section 3 presents the methodology adopted and describes the data sources. Section 4 then describes the main empirical results considering first the extent to which firms strategic choices differ and the characteristics of firms adopting different types of strategic complexity. Through order probit regressions those factors that influence strategic complexity are highlighted and the implications of these on firms' behaviour examined. Section 5 then presents the key findings and conclusions arising from the paper.

2 Conceptual Framework

Without clarification the terms 'corporate strategy' or 'strategy choice' are ambiguous in that it is not clear whether they refer to past, current or future strategy nor indeed to formal written strategy or to implemented strategy. In this paper strategy choice is measured by the implemented market behaviour of firms in the period 1995 to 1998. Market behaviour is interpreted as a proxy for market positioning, which is a measure of firm's effectiveness and success in their markets (Macrae, 1991; Wynarczyk et al., 1993; Storey et al. 1989; Birley and Westhead, 1990; and Siegel et al., 1993). Hambrick suggests that market structure limitations, as characterised by the product life cycle model, "limit the range of maximally feasible strategies, such as that it simply is not true to say that all generic strategies are equally viable within an industry (1983:702). *De facto* this implies that differences will exist in the *technology and* strategy used by firms in different industries as each industry will be at a different stage in the product life cycle. For example, firms operating in dynamic and fast growing market environments will face markedly different competitive forces to firms in mature and stable markets.

A considerable body of literature exists on the properties of markets at different stages in their evolution. For example, growing markets are typified by sales growth, both in the industry or market and individual firms as they increase their market share (Porter, 1980; Catry and Chevalier, 1974), high levels of new firm entry

(Levitt, 1965) and product and process innovations (Patton, 1959). In contrast, mature or declining markets are characterised by market saturation that restricts industry sales growth and limits the potential for increases in market share.

Miller et al. (1996) suggest that in the absence of market threats or resource shortages, firms in a mature market environment will tend to simplify their strategic repertoires and pursue increasingly focused or *simple* strategies (Miller, 1990; Miller and Chen, 1993). Typically, such competitive strategies will focus on achieving economies of scale (Staudt, Taylor and Bowersox, 1976) with limited product differentiation and an augmented focus on pricing strategies (Levitt, 1965). In contrast, multi-dimensional or *complex* strategies may be more suited to more dynamic markets and include high-risk strategies based on product and market differentiation (Patton, 1959) and the search for super-normal profits (Buzzell, 1966, Smallwood, 1973).

In what follows, a typology of business strategy is adopted that draws on the framework proposed by Miller et al. (1996) and makes the distinction between simple and complex business strategies to explore strategy choice and its relationship to the market environment, internal firm characteristics and the adoption of AMT. The complexity of firms' business strategy is measured along two dimensions namely, the percentage of firm's sales attributable to new[i] products introduced by the firm between 1995 and 1998 and the percentage of sales due to products being sold into new geographical markets over the same period[ii]. Using these two dimensions, four strategic options were available to the firms' during the 1995 to 1998 period. First, a stationary strategy where no new products have been developed and no sales have been made to new geographical markets. Second, a simple strategy where new products have been introduced to the market by the firm but no new geographical markets for the sales have been developed. Third, also a simple strategy where no new products have been introduced by the firm but new geographical markets have been developed; and fourth, a complex strategy combining both the introduction of new products and the development of new geographical markets by the firm.

As previously suggested, the institutional organisation literature argues that firms' choice of strategy is largely determined by non-strategic market structure or

industry factors. From this perspective, market dynamics will determine firms' strategy with variations in strategy only being evident between different markets. Therefore, through time firms in the same market will eventually adopt the same strategy, that is, existing differences will be eliminated as firm's strategies converge. Strategy in this context is formulated deliberately and sequentially, being determined at senior management level and then implemented sequentially at lower levels of the organisation through the available mechanisms (Mintzberg, 1979). In this context, technology is viewed as one of the mechanisms in implementing the preferred strategy. Hence we would expect that:

> *Hypothesis 1* – The complexity of firms' business strategy will vary systematically with the dynamism of the market structure or industry in which the firms are operating

In contrast, resource-based perspectives argue that firms' choice of strategy will be driven by their internal capabilities. For example, firms with strongly developed design and R&D capabilities may seek competitive advantage through superior product quality (Porter, 1980). Similarly, where there is 'administrative slack' in a firm this may discourage the adoption of a focused and simple strategy by allowing an organisation to pursue a wider variety of activities such as advertising, R&D, engineering and training (Levinthal and March, 1981; March, 1981; Nelson and Winter, 1982). Yet, for small firms, limited managerial resources will constrain the ability of firms to adopt complex, multi-dimensional strategies (Variyam and Kraybill, 1993) with the background and attitudes of the owner-managers affecting both the firm's strategic capacity and attitude to risk taking (Wozniak, 1987). As the data analysis deals exclusively with small firms this suggests that:

> Hypothesis 2 - Firms with a richer resource base will tend to adopt more complex strategies.

Mauri and Michaels (1998) have attempted to synthesise the industrial organisation perspective with the resource-based perspective on strategy formulation. They conclude that while firms' resource endowments may determine strategy success, strategy choice is – as the industrial organisation literature suggests –

restricted by market structure. In terms of technology they suggest that "firms competing in the same industry tend to develop homogeneous competitive strategies for investing in technology and marketing resources"

In contrast to the industrial organisation perspective and the findings of Mauri and Michaels (1998) Hill argues that the use of AMT by firms in mature markets, where previously differentiation was not a feasible strategy, can "make learning effects significant again" (1988:409). AMT enables firms not only to improve their performance but also to achieve economies of both scale and scope. Based on this argument, the dominance of market structure as a determinant of firms' choice of business strategy has been diminished through new technologies that increase firms' strategic options. It follows that:

> *Hypothesis 3* – Firms' adoption of AMT will stimulate strategic complexity, irrespective of market structure

3 Methodology

The empirical analysis is based on data from the Competitive Analysis Model (CAM) database. CAM has been involved in providing benchmarking information to small firms in Ireland since 1995 and to date, in conjunction with the Industrial development agencies in Northern Ireland and the Republic of Ireland have worked with over 1200 small firms. Data used in this paper was derived from interviews undertaken between 1998 and 1999 as part of the CAM benchmarking service. All of the firms used in the analysis were independently owned small firms with between 10 and 100 full-time employees, had been trading for at least four years and had been identified as having significant growth potential. To this end samples were constructed with the assistance of the appropriate development agencies in Northern Ireland (LEDU – the Local Enterprise Development Unit – and the IDB – Industrial Development Board) and Enterprise Ireland (formerly Forbairt) in the Republic of Ireland. Analysis in this paper is based on 383 firms, 310 (80.9 per cent) in Northern Ireland and 73 (19.1 per cent) in the Republic of Ireland[iii].

For the purposes of the benchmarking exercise information collected from the firms included the following:

(a) full ***accounting information*** for the 1996 to 1998 period;

(b) ***company characteristics*** such as date established, number of employees and primary product markets;

(c) ***owner-manager chara***cteristics, for example, if the owner-manager was involved at the formation of the firm, their current equity share, their willingness to share ownership and power, their age, qualifications and previous work experience;

(d) ***product specific information*** including the nature of product innovation activity and perceived product quality;

(e) ***market information*** including the destination of sales and details of their customer and supplier base;

(f) ***human resource issues*** including the managerial team and employee specific measures;

(g) ***technology usage*** including the age of capital equipment, capacity utilisation and the adoption of both process and organisation Advanced Manufacturing Technologies (AMT)

(h) ***strategy choices*** incorporating both strategic priorities and the means of achieving their strategic goals.

The empirical analysis draws on this benchmarking information to determine strategic complexity, internal characteristics and resources in the firm and the adoption of AMT. Information on the market structure in which the firms were operating could not be determined through the questionnaire data and was therefore assimilated through official economic data sources.

As the sample of firms spanned both Northern Ireland and the Republic of Ireland, industry information was collected separately for both areas. Official government publications[iv] and comprehensive survey information[v] provided information on market sales growth 1993 to 1997, business expansion (sales growth) 1993 to 1997, increase in business market share 1993 to 1997, the level of product innovation activity 1997 and the incidence of R&D activity 1997. Given the diversity of markets in each broad (2-digit) Standard Industrial Classification (SIC), all of the above was collected at the 4-digit SIC level.

4 Empirical Analysis

4.1 Strategy choice

The framework for firms' strategy choice or strategic complexity defined in Section 2 distinguishes four possible strategies:
(i) changing nothing i.e. no product innovations P=0, and no market developments M=0.
(ii) changing product portfolio only i.e. P>0 and M=0.
(iii) changing market portfolio only i.e. P=0 and M>0.
(iv) changing both the product and market portfolio ie. P>0 and M>0.

In terms of the distinctions made by Miller et al. (1996), (ii) and (iii) of these strategic choices might be regarded as 'simple' one-dimensional strategies, with option (iv) reflecting a more 'complex' multi-dimensional strategy. On this basis it is possible to divide firms in the sample into those pursuing each type of strategy over the 1995 to 1998 period (Table 1). What emerges is that for the sample of 383 firms, no strategic option is dominant. 28.5 per cent of firms adopted a static strategy between 1995 and 1998. 44.1 per cent of firms adopted a simple strategy, that is, 25.8 per cent of firms basing their simple strategy on a changing product portfolio and 18.2 per cent focusing on market development. The remaining 27.4 per cent of firms adopted a complex strategy with changes to both their product and market portfolios over the 1995 to 1998 period.

The diversity of strategy choice between the firms refutes the argument by Variyam and Kraybill (1993) that limited managerial resources in small firms would constrain their ability to adopt complex strategies. Instead, over a quarter of small firms had adopted complex strategies between 1995 and 1998. Test statistics on the distribution of firms in each of the categories (Table1) shows that the sample was not evenly distributed between the different strategic options. One reason for this may be the characteristics of the firms. The characteristics of firms adopting each type of strategic option are outlined in Table 2. These characteristics are sub-divided into

factors external to the firm, i.e. market indicators, internal characteristics and resources of the firm and performance indicators over the 1995 to 1998 period.

In general, firms adopting more complex strategies tended to be operating in industries with higher levels of innovation and R&D activity and expanding gross output. Output per business had however decreased over the 1993 to 1997 period for those firms with more complex business strategies. This is reflected in the change in market share variable, with marginally lower increases in market share for these firms with more complex business strategies.

Differences were also apparent in the internal characteristics and resources of firms adopting different strategic options (Table 2). Firms with more complex strategies were, on average, younger and employed slightly fewer workers. As expected, new products and new markets accounted for a larger proportion of sales for those firms with more complex strategies. Larger proportions of firms in the complex strategy grouping had adopted Management Information Systems (MIS) and Management Accounting Systems (MAS). Formal quality accreditation was also more common among these firms with graduates occupying a larger proportion of the workforce than otherwise found. In addition the average age of capital in these plants was also slightly younger.

Significant differences in performance were evident between the strategy groups. In particular, firms adopting more complex strategies had significantly higher turnover and employment growth over the 1995 to 1998 period. Significant differences were less apparent for measures of profitability between the groups, however the data suggests that firms pursuing more complex strategies were sacrificing profit for growth. Consequently, comparatively lower profitability and higher investments in technology – as suggested by the lower average age of capital – together explain the large differential between those firms with high strategic complexity and other firms' measure of return on assets.

4.2 Determinants of Strategic Complexity

While information on the diversity of firms' strategy choice and the characteristics of firms making each of these choices is useful, the role of technology and its relationship to strategy remains unexplored. As outlined earlier, there are two very clear perspectives on the role of technology in business strategy formulation. The industrial organisation perspective argues that technology is merely a tool that implements business strategy, with strategic choice being dictated by the market or industry structure in which the firm is operating and then translated into the objectives of the firm. Once the strategic direction has been determined in the firm, technology and other resources merely fulfil the strategic goals. In contrast to this perspective, resource-based writings argue that it is the internal resources available within a firm that determine the success or otherwise of different strategic options. Even here, technology represents only one determinant of strategy choice.

Based on existing work, therefore, it would be inaccurate to look solely at the relationship of technology to strategy without allowing for the other factors that might be influencing firms' strategy choices. In addition, the results from Table 2 suggest that differences exist in the market structure, firm characteristics and internal resources and performance between firms in each of the strategic complexity groupings and for this reason it is important to include these factors in any analysis of the technology-strategy link. To identify whether or not AMT is affecting strategic complexity, an ordered probit model is used. This model allows for ordering of the dependent variable - strategic complexity - and differentiates between each of the factors included in the model to estimate their influence on strategy choice.

In examining the role of AMT in strategy choice, AMT is sub-divided into process-related technologies and organisation-related technologies. Information on whether or not firms were using a range of process and organisation AMT was collected through the company interviews. Process AMT comprised, computer numerically controlled machine tools (CNC's), Robotics, Automated Materials Handling equipment (AMH), Computer Aided Design (CAD), Computer Aided Production Management (CAM) and Computer Integrated Manufacturing (CIM).

Organisation AMT comprised Quality Certification, Total Quality Management (TQM), Quality Circles and Just-in-Time (JIT) production.

Limited financial resources in small firms may limit the adoption of each of the process-related technologies. For example, as CNC, CAD and to a lesser extent CAM are technologies that can be dedicated to specific tasks, these can be introduced incrementally into the firm. In contrast CIM, is more difficult to implement, being more costly and demanding a higher level of co-ordination between manufacturing activities than would otherwise be necessary.

AMT adoption may therefore be a gradual process in small firms, and this is illustrated by the percentage of firms in the sample having each of the process-related AMT's. CAD was the most widely used AMT, being found in 47.9 per cent of firms. 42 per cent were using CAM and 28.9 per cent were using CNC's. AMH and robotic equipment were less common among the firms, being present in only 20.7 per cent and 6.2 per cent respectively. As already stated, where CIM is used, this will lead to the integration of existing activities with this having direct benefits for the firms. "Integration shortens lead times, encourages design for manufacturability, and makes feasible the production of small batches of customized goods. At the same time closer integration increases interdependence within and across organizational subunits, … [and] encourages quick adjustment to variations in the workflow" (Zammuto and O'Connor, 1992: 708). The fact that only 15.6 per cent of firms were using CIM has implications for the benefits that these firms could achieve from using process-related AMT. Where AMT's are not integrated by CIM, the benefits will be in the form of productivity improvements as opposed to flexibility gains (Jaikumar, 1986).

The incorporation of organisation-related AMT in the analysis builds on research suggesting that process- and organisation-related AMT are intricately linked. Zammuto and O'Connor (1992; 709-710) argue that "Plants having 'lean' production systems – those in which the workers had broadly defined jobs that emphasized quality and teamwork coupled with JIT manufacturing practices – were more productive. … Broader jobs, enhanced communication, and decentralized decision making increase the potential for the flexible use of AMTs, improving an

organization's ability to respond quickly to changing product requirements and market conditions". This suggests that process-related AMTs provide the potential to increase strategic complexity, but this will only be realised where the organisation's structure is conducive to changing manufacturing practices.

Starting with a broadly based exploratory analysis of the data, a group of 19 explanatory variables were identified, which were significant in determining firms' strategic complexity. Table 3 gives the results of ordered probit regressions of the complexity of firms' strategy between 1995 and 1998 on a range of market industry structure indicators, firm characteristics and internal resources measures and process AMT and organisation AMT indicators (Equation 1). To overcome problems of multi-collinearity and to eliminate those factors that were less important in determining strategic complexity, some more insignificant variables were dropped and the probit models were re-estimated (Equations 2 and 3). Each of the equations were significant at the 1 per cent level using a Chi-square test, and the signs and significance of individual variables proved robust to changes in specification. The percentage of predictions in each of the equations are similar and are consistent with other studies of this type.

From the probit models it is clear that the level of strategic complexity adopted by firms between 1995 and 1998 was greater for those firms in market sectors (defined at a 4-digit SIC level) with higher levels of innovation activity. Increased levels of product innovation is associated with growing and dynamic markets (Patton, 1959). As markets grow there are significant opportunities for product innovations either through modifications to existing products or the development of new products. With these product changes new customers may be identified and therefore firms adopt a complex strategy with changes to both their product and market portfolios.

Increased strategic complexity was also associated with declining market share over the 1995 to 1998 period. While declining market share is usually associated with mature markets (Catry and Chevalier, 1974), Table 2 highlighted that firms adopting more complex strategies were operating in faster growing markets. Sales growth for firms in these markets however, was not increasing as fast as the market rate of growth, and therefore firms' market share over the period was

declining. These firms were therefore operating in dynamic markets where the entry of new firms was driving down their share of total sales.

Market influences, that is, innovation intensity and changes in firms' market share, demonstrate that in more dynamic markets firms will tend to adopt more complex strategies. This provides some support for Hypothesis 1 that strategic complexity will increase with increased market dynamism. This finding also supports the proposition of Miller et al. (1996) that firms in mature markets will tend to simplify their strategic repertoires and pursue increasingly focused or simple strategies, while firms in more dynamic markets will adopt more complex strategies. Further, these findings also support, in part, the industrial organisation perspective on convergence of strategies in similar market structures. In contrast to the industrial organisation perspective however, Table 3 also demonstrates that other factors are important in determining strategic complexity beyond that of market influences.

The resource based perspective on strategy formulation and complexity was examined by incorporating a range of variables on the firms' characteristics and internal resources into the regression. These included: performance measures of firm growth, profitability and productivity; firm characteristics such as age and size; market characteristics including the competitive pressures associated with customers, labour, raw material supplies and finance, the barriers to entry into the market and the location of the firm. As entrepreneurial characteristics have been identified as central to the success of small businesses (Wozniak, 1987; Barkham, 1992; Johnson, 1991; Kinsella et al., 1993) a range of measures related to the entrepreneur were also included in the model. Lack of significance for most of these measures meant that they were eliminated from equation 1. Of those remaining, the only significant variable in determining strategic complexity was firm age, with younger firms tending to have more complex strategies. These findings fail to support Hypothesis 2 and instead, in conjunction with the findings in Table 2, suggest that while differences in characteristics and internal resources may exist between firms adopting different levels of strategic complexity, these are not important (with the exception of firm age) in determining strategic choice. Other research also suggests that firms' characteristics and internal resources are less important in determining strategy choice

than in influencing the success of the chosen strategy (Hewitt-Dundas and Roper, 2000).

The incorporation of process-related and organisation-related AMT into the regression created some interesting findings. Initially 10 AMTs were included in the regression, however, lack of significance associated with the adoption of robotic equipment and quality circles led to their exclusion from the regression and a re-estimation of the model[vi]. Computer Aided Design (CAD) was also excluded from equation 2 due to its correlation with Computer Aided Production Manufacturing (CAM)[vii]. Similarly, quality certification and JIT production were also excluded from the estimation of Equation 3 due to their strong correlation with TQM[viii]. Re-estimation of the model allowed the effects of each of the remaining AMTs on strategic complexity to be seen more clearly (Equation 3).

Four of the AMTs were found to have a significant effect on firms' strategic complexity. These included three process-related technologies, namely Computer Numerically Controlled Machine Tools, Automated Materials Handling equipment, Computer Integrated Manufacturing and one organisation-related technology, Total Quality Management. While it would be expected *ex ante* that the adoption of AMT would be directly related to increased strategic complexity, this was not supported by the results[ix]. Indeed, the adoption of CNC's, CAD (equation1) and CAM were related to lower strategic complexity[x]. In contrast, the adoption of AMH equipment, CIM and TQM were significantly associated with increased strategic complexity.

These findings emphasise the fact that AMT is an all-embracing term with considerable diversity between its component technologies. Hill (1988: 409) proposed that the use of AMT enabled firms to "make learning effects significant again" with this facilitating a strategy based on differentiation. Yet, as already outlined, the adoption of AMT is often an incremental process with lower order technologies, such as CNC's, CAD and CAM being introduced to firms as independent technologies with immediate productivity benefits. In contrast, AMH and CIM technologies represent higher-order AMT that leads to integration of the whole manufacturing process and flexibility gains throughout the organisation.

Similarly, TQM represents an organisation AMT that also integrates subunits and facilitates economies of scope and a broader strategy.

These findings lead to the rejection of Hypothesis 3, that firms' adoption of AMT will stimulate strategic complexity irrespective of their market structure. What is found from the regressions is that, AMTs cannot be treated as an homogenous group of technologies with uniform effects on strategic complexity. In particular, the adoption of CNC's, CAD and CAM tend to reduce firms' strategic complexity[xi]. In contrast, the adoption of AMH and CIM, along with the organisation-related AMT of TQM, stimulate greater strategic complexity among the firms.

The ordered probit model has highlighted some interesting relationships between firms' strategic complexity and market structure, firm characteristics and internal resources, and in particular, the adoption of AMT. It is only by taking this analysis a step further, in determining the marginal effects of the ordered probit model, that the actual effect of each factor can be identified. Table 4 presents the Marginal effects for Equation 3 of Table 3 and highlights the effect of each factor on firms with different levels of strategic complexity.

From Table 3, the industry influence of innovation intensity suggested that firms' operating in sectors with higher levels of product innovation tended to adopt more complex strategies. The marginal effects (Table 4) illustrate however that as innovation intensity increases firms with a static strategy or a simple strategy will tend to simplify their strategies while firms with a complex strategy will enhance their strategic complexity. Increased levels of market innovation is therefore associated with a divergence of strategic complexity with only those firms previously using complex strategies capable of keeping pace with market trends.

In contrast to innovation intensity, increases in firm's market share will lead to a convergence of strategies between firms. While the literature suggests that firms experiencing increases in their market share will typically be operating in dynamic markets and adopting complex strategies, this was not supported by the data (Tables 2 and 3). Instead, the results suggested that firms operating in growing markets were experiencing relative decreases in their market share as the entry of new firms into the

market was diminishing their growth in sales compared to the market average. For these firms with complex strategies therefore, strategic complexity is used to consolidate and increase market share with the resulting increases in market share leading these firms to simplify their strategies. In contrast, for those firms with a static or simple strategy, increases in their market share will lead them to adopt more complex business strategies.

Firm age was the only factor relating to the firm's characteristics and internal resources that had a significant impact on determining strategic complexity. In general, older firms tended to simplify their strategies. Marginal effects data suggests that as firm age increases, those firms that had previously adopted a static or simple strategy will increase the complexity of their strategies. In contrast, for those firms that were previously adopting complex strategies, as they get older they will tend to simplify their strategies. Firm age therefore acts as a converging influence on strategic complexity as firms with complex strategies reduce the level of complexity and those with simple strategies increase their level of complexity.

The adoption of AMT also has a different effect on firms' strategic complexity, depending on their current strategic complexity. Yet, again, AMTs cannot be treated as an homogenous group with CNC's behaving differently to AMH, CIM and TQM. The adoption of CNC's is significant to those firms with static or simple strategies in leading them to increase their level of strategic complexity. In contrast, the introduction of CNC's to firms with complex strategies will act as a simplifying influence on their strategies. The adoption of CNC's therefore lead to a convergence of strategic complexity among firms with this being linked to the often narrow application of CNC equipment.

AMH, CIM and TQM act to polarise the complexity of firms' strategies. For example, for those firms with static or simple strategies the adoption of either of these techniques will reduce their strategic complexity while for those firms with complex strategies, the adoption of AMH, CIM or TQM will increase the level of strategic complexity. These 'higher-order' AMTs therefore, lead to a polarising of firm's strategic complexity. As firm's with greater complexity have higher levels of sales and employee growth (Table 2), the implication of this is that the growth differential

between firms with complex strategies and those with simple or static strategies will widen with the adoption of higher order AMTs. While firm's with complex strategies were sacrificing profit for growth, it is likely that this would be a short-term phenomena as the flexibility benefits of AMT would enhance the firms' market position, leading to increases in market share and subsequently to increases in profitability[xii].

5 Conclusions

The properties inherent in Advanced Manufacturing Technology (AMT), create new opportunities for firms, and in particular small firms. The capability of these technologies to modify production specifications quickly and accurately means that firms can customise their products and attain economies of scope based on low volume and low cost production. While traditionally technology has been perceived merely as a tool in implementing business strategy, AMT has the potential to directly affect firm's strategy choices. To date however, empirical analysis to examine the technology-strategy relationship has not been forthcoming (Parthasarthy and Sethi, 1992). This paper has attempted to address this gap in the literature by synthesising current perspectives on the factors that determine strategy choice and so, integrate technology into the analysis. A typology of strategy choice was used based on the simple-complex framework as proposed by Miller et al. (1996) and suggested that firms in a growing and dynamic market environment would adopt multi-dimensional, complex strategies while firms in a mature market would use simple strategies.

Based on a sample of 383 small firms, a number of key findings emerge from the data and are now summarised. Small firms do not behave uniformly in their strategic choices. 28.5 per cent of firms adopted a static strategy of no product or market development between 1995 and 1998. 44.1 per cent adopted a simple strategy of either changes to their product or market portfolios, while the remaining 27.4 per cent of firms adopted a complex strategy of both product and market development. Those firms adopting complex strategies tended to be in more dynamic markets, were younger, employed slightly fewer people and had higher levels of sales and employee growth over the 1995 to 1998 period.

Through ordered probit regressions market structure was identified as having a significant relationship with strategic complexity. That is, firms in growing and dynamic markets tended to adopt more complex business strategies. Firm's characteristics, internal resources and factors specific to the entrepreneur were not significantly related to strategic complexity. The exception to this was firm age where younger firms tended to adopt more complex strategies.

A significant relationship was found between the adoption of AMT and the strategic complexity, however, this acted in different ways, depending on the specific technology. For example, two types of AMT were identified, lower-order technologies such as CAD, CAM and CNC's, and higher order technologies such as AMH, CIM and TQM. The lower-order AMTs can be introduced incrementally into the production process and be dedicated to specific and narrow tasks with immediate productivity gains. These technologies tend to be associated with lower levels of strategic complexity. The higher-order AMTs demand the integration of manufacturing sub-units and result in an increase in strategic complexity and the attainment of competitive advantages based on flexibility gains.

Analysis was made of the marginal effects of each of those variables identified as having a significant relationship with strategic complexity. Again, differences were found in the group of AMTs in terms of their impact on the complexity of firm's strategy. The adoption of lower order technologies led to a convergence of strategic complexity between firms, while the adoption of higher order technologies resulted in a divergence of strategic complexity. This suggests that the introduction of higher order AMTs may widen the gap between firms, as firms with complex strategies increase their strategic complexity and those with simple strategies simplify their business strategies. This has important implications given that firms with complex strategies were growing at a significantly faster rate than those with simple strategies.

It can therefore be concluded that, while there is a significant relationship between the strategy that a firm pursues and the market in which it is operating, AMTs may also be instrumental in this relationship. It must not be assumed, however, that AMTs behave uniformly but instead the gains from lower-order technologies and their effect on firm's strategy will differ markedly from higher-order

technologies. In addition, firm's must have an environment that is conducive to the adoption of higher order AMTs, otherwise this will lead to a narrowing of their business strategy and act as a constraint on growth. Alternatively, for firms pursuing a complex strategy, the introduction of AMTs will improve their strategic position by increasing their complexity and leading to flexibility gains in terms of business growth.

Table 1: Firms' strategic choice

		Product Development 0	Product Development 1
Market Development	0	109 (28.5%)	99 (25.8%)
	1	70 (18.2%)	105 (27.4%)

Pearson Correlation Coefficient of .124 with significance at the 0.05 level (2-tailed)
χ^2 = 5.874 with significance at the 0.05 level (2-tailed)

Table 2: Firms' Characteristics by Strategic Choice

Strategic Complexity		No Active Strategy	Simple Strategy	Complex Strategy
MARKET INFLUENCES				
Market Innovation Intensity		43.86	45.20	47.84
R&D in Plant Intensity		47.56	46.91	49.97
R&D Dept in Plant intensity		13.73	15.60	14.38
Change in gross output – 4-digit SIC level	**	142.10	139.55	152.25
Change in output per business		124.02	121.56	110.70
Change in market share	***	0.97	1.0	0.8
FIRM CHARACTERISTICS				
Firm Age (yrs)	***	38.46	22.77	16.83
Number of Employees	***	35.44	46.00	30.47
New Products (% of sales)	***	0	15	34
Sales to New Geographical Markets (% of sales)	***	0.0	11.13	29.59
Concentration of Sales (%)		38	36	44
Number of competitors		18	42	38
Number of suppliers		81	76	43
Management Information System (% of firms)		59.8	72.7	67.0
Management Accounting System (% of firms)		67.9	81.0	82.2
Graduates (% of workforce)		4.83	16.72	19.19
Quality Accreditation (eg. ISO) (% of firms)		35.8	38.3	39.0
Average age of capital (yrs)		5.99	4.87	4.66
PERFORMANCE INDICATORS				
Turnover Growth (%pa)	***	6.31	13.23	36.97
Employment Growth (%pa)	***	2.18	10.82	15.82
Profit Margin (%)		6.82	6.69	-1.74
Return on Assets (%)		119.74	67.72	545.41
Asset to Turnover Ratio		27.70	24.32	47.91

Kruskal Wallis H Test for k-independent samples
* Correlation significant at 0.1 level
** Correlation significant at 0.05 level
*** Correlation significant at 0.01 level

Table 3: Strategic Complexity Equations and System Coefficients

	Strategic Complexity		
	(Equation 1)	**(Equation 2)**	**(Equation 3)**
Industry Factors			
Innovation Intensity (mean %)	0.007*	0.007*	0.007*
	(0.004)	(0.004)	(0.004)
Industry Output Growth	-0.004	-0.004	-0.004
	(0.003)	(0.003)	(0.003)
Business Output Growth	0.003	0.003	0.003
	(0.003)	(0.003)	(0.003)
Average Firm Market Share	-0.881**	-0.904**	-0.847**
	(0.402)	(0.378)	(0.380)
Plant Specific Factors			
Firm Age (yrs)	-0.013**	-0.013**	-0.012***
	(0.004)	(0.004)	(0.004)
Founder still involved with sig.	0.202	0.196	0.203
Equity	(0.187)	(0.180)	(0.179)
Sales Growth (%pa)	0.004	0.004	0.004
	(0.003)	(0.003)	(0.003)
Output per Employee (£000)	-0.002	-0.002	-0.002
	(0.001)	(0.001)	(0.001)
Power of Customers	-0.131	-0.132	-0.141
	(0.116)	(0.116)	(0.113)
Process Technology Usage			
Computer Numerically	-0.285	-0.301*	-0.306*
Controlled Tools	(0.182)	(0.176)	(0.174)
Robotics	0.051		
	(0.427)		
Automated Materials Handling	0.342	0.338	0.344*
	(0.215)	(1.569)	(0.210)
Computer Aided Design	-0.136		
	(0.181)		
Computer Aided Production	-0.205	-0.209	-0.206
Management	(0.178)	(0.176)	(0.176)
Computer Integrated	0.481*	0.450*	0.452*
Manufacturing	(0.271)	(0.261)	(0.261)
Organisation Technology Usage			
Quality Certification	-0.087	-0.095	
	(0.165)	(0.162)	
Total Quality Management	0.757***	0.662**	0.677***
	(0.313)	(0.277)	(0.260)
Quality Circles	-0.248		
	(0.311)		
Just-in-Time Production	0.123	0.112	
	(0.206)	(0.203)	
Constant	2.303	2.367	2.359
Number of observations	226	226	226
χ^2	64.5	63.6	62.9
Log Likelihood	-209.2	-209.6	-209.9
Restricted Log Likelihood	-241.5	-241.4	-241.4
Correct Predictions (%)	53.5	52.6	52.6

Table 4: Marginal Effects From Strategic Complexity Models

Dependent Variable – Strategic Complexity	No Strategic Change	Simple Strategy	Complex Strategy
Industry Factors			
Innovation Intensity (mean %)	-0.002	-0.000	0.002
Industry Output Growth	0.001	0.000	-0.001
Business Output Growth	-0.001	-0.000	0.001
Average Firm Market Share	0.246	0.035	-0.281
Plant Specific Factors			
Firm Age (yrs)	0.003	0.000	-0.004
Founder still involved with sig. Equity	-0.059	-0.008	0.067
Sales Growth (%pa)	-0.001	-0.000	0.001
Output per Employee (£000)	0.000	0.000	-0.001
Power of Customers	0.041	0.005	-0.047
Process Technology Usage			
Computer Numerically Controlled Tools	0.088	0.012	-0.101
Automated Materials Handling	-0.100	-0.014	0.114
Computer Aided Production Management	0.060	0.008	-0.068
Computer Integrated Manufacturing	-0.131	-0.018	0.150
Organisation Technology Usage			
Total Quality Management	-0.197	-0.028	0.225

Marginal effects derived from Table 3, Equation 3 and computed at variable means.

Data Appendix

Description	Definition
1. Market Influences	
Market Innovation Intensity	Defined as the percentage of total sales attributable to the sale of new products, defined at a 4-digit SIC level
Industry Output Growth	Defined as the average increase in sales output between 1993 and 1997 at the 4-digit SIC level
Business Output Growth	Defined as the average increase in sales output between 1993 and 1997 at the 4-digit SIC level
Change in Firm's Market Share	Defined as the change in firm's share of total sales output from 1993 to 1997 at the 4-digit SIC level
2. Firm Characteristics and Internal Resources	
Firm Age (yrs)	The age of the firm in years in 1998.

Founder still involved with Significant Equity	A 0/1 dummy taking value 1 if the founder is still involved in the firm and holds over 20 per cent of the equity, and 0 otherwise.
Sales Growth (% per annum)	Defined as turnover (less any discounts given) deflated by the national rate of producer price growth. The variable is defined as the average real percentage change between 1996 and 1998.
Output per Employee (stg£000)	Defined as the total sales per employee, 1998.
Power of Customers	An intensity index ranging from 0 if customer power was 'unimportant' to 100 if customer power was 'very important'.

3. Process Technology

Computer Numerically Controlled Equipment	A 0/1 dummy variable taking value 1 if the firm had adopted CNC equipment, and 0 otherwise.
Robotics	A 0/1 dummy variable taking value 1 if the firm had adopted robotic equipment, and 0 otherwise.
Automated Materials Handling	A 0/1 dummy variable taking value 1 if the firm had adopted AMH equipment, and 0 otherwise.
Computer Aided Design	A 0/1 dummy variable taking value 1 if the firm had adopted CAD systems, and 0 otherwise.
Computer Aided Production Manufacturing	A 0/1 dummy variable taking value 1 if the firm had adopted CAM systems, and 0 otherwise.
Computer Integrated Manufacturing	A 0/1 dummy variable taking value 1 if the firm had adopted CIM, and 0 otherwise.

4. Organisation Technology

Quality Certification	A 0/1 dummy variable taking value 1 if the firm had acquired formal quality certification, and 0 otherwise.
Total Quality Management	A 0/1 dummy variable taking value 1 if the firm had adopted a TQM philosophy, and 0 otherwise.
Quality Circles	A 0/1 dummy variable taking value 1 if the firm had adopted Quality Circles, and 0 otherwise.
Just-in-Time Production	A 0/1 dummy variable taking value 1 if the firm had adopted a JIT philosophy, and 0 otherwise.

Notes

[i] New products are defined as the proportion of total current sales comprised of products that have been newly introduced to the firm between 1995 and 1998.
[ii] The percentage of sales in new markets is particularly salient in this analysis as Northern Ireland, and Republic of Ireland firms have an over-dependence on the home market.
[iii] The sample bias towards Northern Ireland firms reflects primarily a greater level of encouragement for firms to participate by the Northern development agencies. See Barkham et al, (1996) for a survey of the performance characteristics of Northern Ireland firms compared to some other UK regions, and Gudgin et al (1995) for a survey of the relative performance of small businesses in Northern Ireland and the Republic of Ireland.
[iv] For Northern Ireland firms information on 4-digit sales growth, business growth and changing market share from 1993 to 1997 was obtained from Office for National Statistics, Business Monitor PA1002, Production and Construction Inquiries - Summary Volume, 1997. Similar information for Republic of Ireland firms was obtained from Statistical Bulletin 1999, Vol. LXXIV. No.4.
[v] Information on innovation and R&D activity across market sectors was obtained from the Product and Process Development Survey, 1998 which was a representative sample of 752 Irish firms (Roper. S & N. Hewitt-Dundas, (1998) "Innovation, Networks and The Diffusion of Manufacturing Best Practice," NIERC Report Series No. 14, NIERC, Belfast).
[vi] Only 6.2 per cent of the firms had adopted robotic equipment and 13.5 per cent having quality circles.
[vii] A Pearson Correlation Coefficient of .191 with significance at the 0.01 level (2-tailed) was found between the adoption of CAD and CAM
[viii] A Pearson Correlation Coefficient of .154 with significance at the 0.01 level (2-tailed) was found between the adoption of Quality Certification and TQM, with a coefficient of .415 and significance at the 0.01 level (2-tailed) for JIT and TQM.
[ix] The rationale for this assumption is based on the inherent competencies of AMT to shorten production runs, reduce lead times and facilitate economies of scope based on low volume and low cost.
[x] It should be noted that of the relationship between these three technologies and strategic complexity was only significant for the use of CNC's.
[xi] It should be noted that this negative relationship between the adoption of AMT and strategic complexity was only significant for CNC's.
[xii] For a discussion of the relationship between capital investment and profitability and profitability and market share, see Buzzell and Gale (1987).

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